

Nurturing Nanoscience

The Kavli Nanoscience Institute at Caltech

For over a decade, the Kavli Nanoscience Institute (KNI) at Caltech has been an intellectual hub and facilitator of cross-disciplinary research in the areas of nanoscience and nanotechnology. It houses an advanced nanofabrication facility that supports the research endeavors of many Caltech and Jet Propulsion Laboratory (JPL) researchers and has been critical to realizing exciting breakthroughs in nanoscale photonics, materials science, and biotechnology. *ENGenious* sat down with the KNI's two Fletcher Jones Foundation Co-Directors, Professors Oskar J. Painter and Nai-Chang Yeh, as well as the KNI's Associate Director of Business Operations, Mary Sikora, to discuss the past, present, and future contributions of this intellectual hub.

ENGenious: How has the purpose of the KNI evolved since its creation?

Yeh: Nanoscience and technology was starting to become an important interdisciplinary research area at the time the KNI was created, and a lot of the research required very expensive facilities. Thus there was a sense that it would be much more productive if we could create a centralized facility that housed a variety of instruments for nanoscience and technology research. As we brought multi-disciplinary researchers together, they would come up with new ideas, and the KNI evolved into an intellectual hub. Initially, the KNI members' research focused on nanophotonics and nano-biotech, and then, as time passed, the opportunities for nanoscience and technology became broader

and broader. Now we are facilitating work on the frontiers of nanoscience and technology research, particularly in areas of quantum science and technology, bio- and medical engineering, renewable energy and sustainability, and space exploration and astronomy.

Sikora: When I came on board in late 2005, we were still building and planning the facility. We were also trying to grow the community, but the main focus was the renovation of the sub-basement of Steele Lab.

Painter: From the beginning, it was clear that the creation of the KNI was going to be an exciting opportunity for many of us to conduct nanoscience research. Michael Roukes, the first director of the KNI, and Axel Scherer, who later became a

co-director, were instrumental in the genesis of the KNI. They started by acquiring an industrial electron beam lithography system. Previously, most university facilities were limited to small scanning electron microscope tools that were retrofitted to do lithography, greatly limiting the fidelity and throughput of the features being made. This new tool, which Michael and Axel made available to a community of users (not the norm at the time at Caltech), enabled one to do nanoscale fabrication on the scale of a six-inch wafer, integrating many devices together over multiple steps of lithography. This was prior to the establishment of the KNI, and it was a pivotal moment at Caltech both in the sense of the new technology available to do science and also in the culture.

ENGenious: How do you know that the KNI has been successful?

Yeh: The facilities have enabled lots of research activities by groups around the campus, from JPL, and also from industry and local universities. To get a more concrete sense of this, we did an estimate of how much Caltech research funds have supported people using the facility since it opened.

Painter: It has been roughly \$150 million over 10 years. That's an impressively big number for a place the size of Caltech. It's a little bit scary, actually, because as a co-director you quickly realize how important it is to make sure this facility is running optimally, since it is so critical to everyone's research now. Before the creation of the KNI, everyone had

their own clean room to do their own nanofabrication or microfabrication. The KNI has been a total remodel for Caltech in many ways, and the estimate of research funds used shows the vitality and the importance of the facility and the approach.

Yeh: Every year, we have on the order of 100 users from five different divisions at Caltech, as well as 20 to 30 research groups that professorial faculty members are affiliated with. We also host international workshops, symposia, and tours.

Sikora: We hosted the first TEDx event on the Caltech campus. The KNI organized it because of the connection of nanoscience to Richard Feynman. The event was sold out! Five of the talks made it to the TED

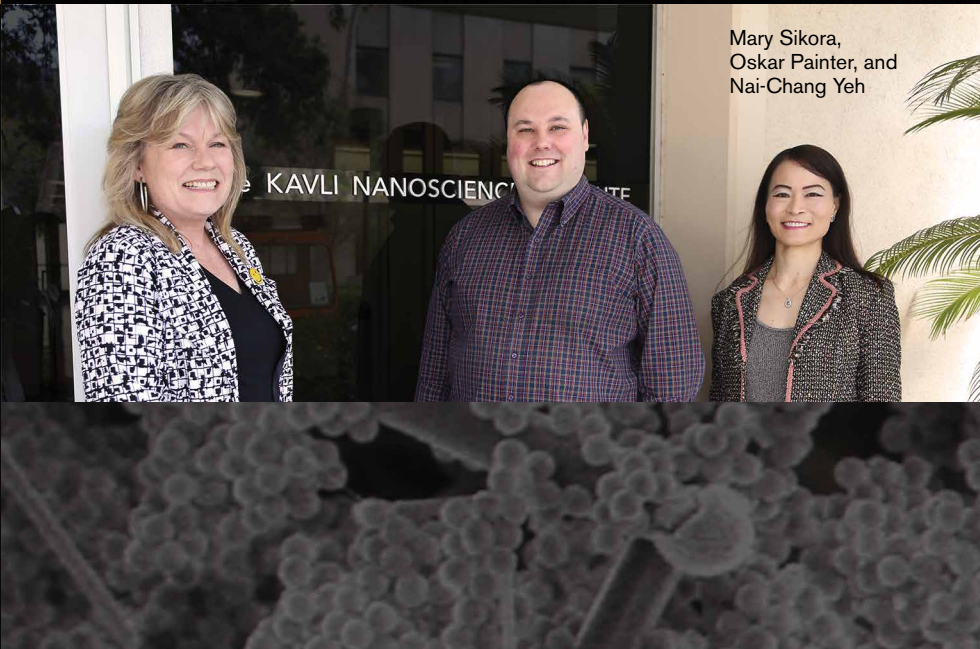
channels. There was so much energy in the air that day and everyone was so excited about what was happening on campus. That event led to a new way to describe science. Through post-event surveys, we discovered that for approximately 25% of the audience members, it was their first time on the Caltech campus. The event was livestreamed and had more than 21,000 unique views. We had a second TEDxCaltech event in 2013, and in total, the talks from both events have had more than three million hits just on YouTube. This translates into an amazing amount of outreach!

Yeh: We're not just running facilities. We are creating an environment that nurtures nanoscience and technology.

ENGenious: What are you doing to ensure the continued success of the KNI?

Painter: The KNI is an enabling resource. We're trying to think beyond just the facility. What is the meaning of the KNI? What are the real horizons in nanoscience, and where do we see that going in the future? Because it's such a broad field, it's sometimes hard to articulate, but we're working on trying not just to have the facility but to have this community, this environment, that can help nurture these various aspects of nanoscience as well.

Yeh: Since we acquired our industrial electron beam lithography tool, a lot of universities have caught up to us, and we're thinking about how to reinvent ourselves in such a way that we will continue to lead the pack in the future. We recently put in a proposal to the National Science Foundation to get a special focused ion beam system that uses very light atoms, helium and neon, to do extremely fine three-dimensional cutting and patterning of materials. It directly sculpts your three-dimensional mask. It's like an Etch A Sketch, but at the atomic



scale. There's only one other university in California that has such a tool. I see that as being another moment where we're really going to advance the capability here at Caltech. This new tool enables researchers to do things they never could have done before.

ENGenious: How are your roles different? Is there a secret behind your team's success?

Yeh: Oskar and I always consult with each other, work on things together, and, if necessary, take the blame together. Mary has been marvelous; she helps with all kinds of things, and Guy DeRose, the KNI Associate Director of Technical Operations, takes good care of the staff members and the day-to-day operation of the facilities.

Painter: The constants throughout the years have been Mary and Guy; they've worked with all the co-directors since the inception of the KNI. We really rely on the expertise of Mary and Guy, as well as the rest of the excellent technical and administrative staff of the KNI. We have a relatively lean staff that does a huge amount of work, if you compare it to other institutes of similar size.

Sikora: The staff is really great. They're quite dedicated, and they will answer pleas from people who can't get equipment to work at all hours and on the weekends. We have good team spirit! Also, I like that my job is different every single day.

Painter: The other thing that's very special about the KNI, and I think Caltech in general, is that the students and postdocs play a vital role. Our pseudo-staff are our students and postdocs that help optimize fabrication techniques, improve the running of the equipment, and invent entirely new methods for using our equipment. They also help teach our technical staff these new methods and

help in the training of new students. So it's very much a communal atmosphere.

ENGenious: How does the KNI serve nanotechnology startup companies?

Painter: When I graduated from Caltech, I started a company with Kerry Vahala and Amnon Yariv. At the time, we used a good portion of our A-round of fundraising to build our own clean room. Today, with the presence of the KNI, as a faculty member it's much easier to think about starting a company using the KNI as a cost-effective means to create proof-of-principle devices. But there's always a balance between serving industry and serving students and faculty on campus. Right now, I think we are in a sweet spot. We have a good amount of industrial users, and they don't tend to monopolize any of the equipment. I should add that the benefits can also go both ways; there's the potential for the cross-fertilization of ideas between academic innovation and industrial "know-how."

ENGenious: What's next for the KNI?

Yeh: If we continue to build up our endowments, we'd like to give seed funds to people who have brilliant new ideas that cannot immediately get federal grants. We are starting with a smaller program, the KNI-Wheatley Scholarship. We plan to support one junior faculty member every year with \$25,000 in discretionary research funds for new and innovative projects. Then we are hoping to expand the program so it isn't limited to junior faculty.




Painter: At a technical institute like our own, the most important thing that comes out of any sort of group like the KNI is the science. The areas of science that connect to nanoscience and the KNI are myriad, ranging from materials and renewable energy

research to biology. One area that is currently benefiting greatly from nanoscale research at the KNI is quantum physics, where the science and engineering of new quantum materials, information processing systems, and sensors are rapidly progressing. In general, I am very excited by the scientific opportunities I see on the horizon for the KNI.

ENGenious: How are the KNI and the JPL Microdevices Laboratory complementary?

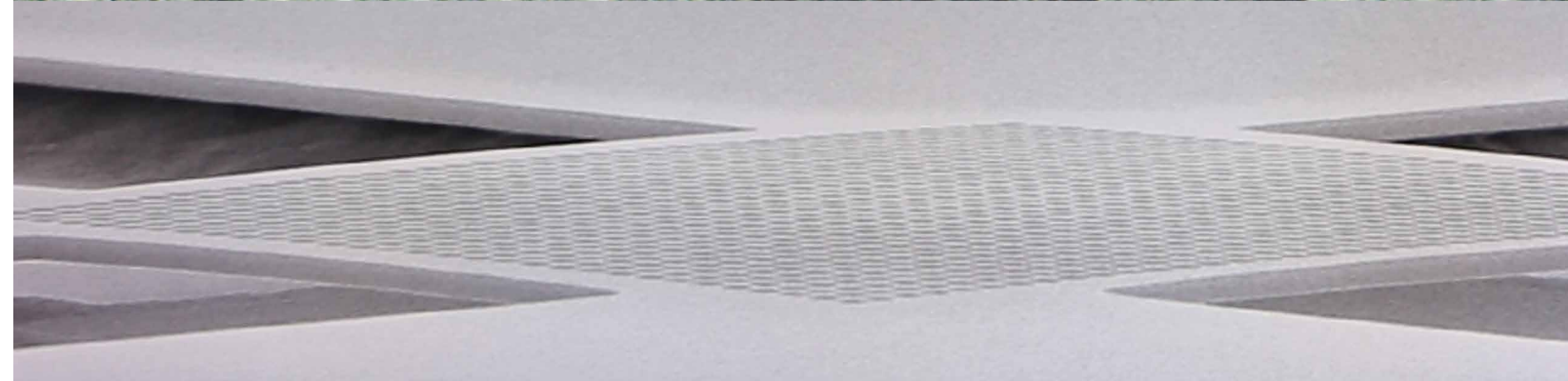
Painter: They have an amazing facility at JPL. At the KNI, we have some tooling and some ways of doing things that are different and complementary. In some ways, our facility is a little freer in terms of what processes you can run and how accessible different tools are. Of course, we don't have the same sort of demand on us in terms of the reliability of our processes. At the KNI, you can fail a little bit more, which means you also get to explore more things.

ENGenious: What do Caltech alumni need to know about the KNI?

Yeh: The KNI has nurtured a new generation of scientists and engineers in nanoscience and technology. And it's incredibly cross-disciplinary; this is an area that can always have a major impact on the world. Caltech alumni are welcome to tour the facilities and learn more about what we have been doing for Caltech, for education, for research, and for frontier endeavors.   

Oskar J. Painter is the John G Braun Professor of Applied Physics and Fletcher Jones Foundation Co-Director of the Kavli Nanoscience Institute. Nai-Chang Yeh is Professor of Physics and Fletcher Jones Foundation Co-Director of the Kavli Nanoscience Institute. Mary Sikora is Associate Director of Business Operations for the KNI.

Visit kni.caltech.edu.



These research images were created using the Kavli Nanoscience Institute's advanced nanofabrication facility. The scanning electron micrographs in the top image reveal the fine-scale structure responsible for the iridescent qualities of an *Urbanus proteus* butterfly wing. The middle image is of a photonic crystal nanomembrane formed from a silicon-on-insulator. Light is trapped within the silicon membrane due to the nanoscale etched air holes. The bottom image illustrates nano-pillars.